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By David A. Hilton, Herbert R. Henderson, and Ben W. Lawton

April 1975

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16. Abstract

This paper documents the field noise measurements, obtained at the request of the US Air Force, of the Cessna 02-T turbine powered propeller airplane. The main objective of the study was to obtain the basic noise characteristics of this aircraft during static ground runs and flyover tests, to identify the sources of noise, and to correlate them with the airplane operating conditions.

The results are presented in the form of overall noise levels, radiation patterns, and frequency spectra. Also included herein is a comparison of the noise characteristics of the present turbine powered propeller airplane with those previously obtained on the reciprocating engine powered version.

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GROUND NOISE MEASUREMENTS DURING STATIC AND FLYBY OPERATIONS OF THE CESSNA O2-T TURBINE POWERED AIRPLANE

By David A. Hilton, Herbert R. Henderson, and Ben W. Lawton

INTRODUCTION

This paper documents the field noise measurements, obtained at the request of the U.S. Air Force, of the Cessna O2-T turbine powered propeller airplane. The main objective of the study was to obtain the basic noise characteristics of this aircraft during static ground runs and flyover tests, to identify the sources of noise, and to correlate them with the airplane operating conditions.

The results are presented in the form of overall noise levels, radiation patterns, and frequency spectra. Also included herein is a comparison of the noise characteristics of the present turbine powered propeller airplane with those previously obtained on the reciprocating engine powered version of reference 1.

APPARATUS AND METHODS

Test Airplane

The test airplane for the studies of this paper is a 4500 lb gross weight, high-wing, monoplane powered by two Allison Model 250-B15, 330 shaft horsepower turbines. This propulsion system is uniquely configured; one turbine being nose mounted and driving a tractor propeller and the other turbine being rear mounted and driving a pusher propeller. The propellers on each engine are of a constant speed type having three blades and a diameter of 84 inches. The propellers are identical in respect to chord and pitch distributions. The photographs of figure 1 show the turbine powered O-2, which will hereafter be referred to as the O-2T. A three-view line drawing with a list of the principal physical dimensions of the O-2T airplane is presented in figure 2. Aircraft and pilot were provided for the tests by the Cessna Aircraft Company, manufacturer of the airplane.

Test Conditions

Noise measurement tests were conducted on January 15, 1969, at the NASA Wallops Station where use was made of the main paved runway surface and the associated flat terrain for locating instrumentation and for obtaining both static and flyby noise data.

Typical terrain features of the Wallops Station area are shown in the photograph of figure 3 which is a view looking west from the end of runway 10-28.

A photograph of the microphones in position for the static tests is shown in figure 4. A schematic diagram of the microphone arrays for the static and flyby tests is illustrated in figure 5. All measurements were made in accordance with the recommendations of reference 2.

Noise Measuring Equipment

The noise measuring instrumentation for these tests is illustrated by the block diagram of figure 6. Two recording stations having three microphones each were employed during the static noise measurements. One of these stations was used during the flyover noise measurements. All microphones were of a commercially available piezo-electric ceramic type having frequency responses flat to within ± 3 dB over the frequency range of 20 to 12,000 Hz. The outputs of all microphones at each station were recorded on multi-channel magnetic tape recorders. The entire sound measurement systems were calibrated in the field before and after the acoustic measurements by means of commercially available discrete frequency calibrators. The data records were played back from the tape to obtain the sound pressure level time histories and both broad band and narrow band spectra.

Aircraft Operation

Noise measurements were taken of the aircraft under static run-up and flight conditions, recording individually the front engine, the rear engine, and both engines simultaneously. For both static and flyover tests the propeller rpm was held constant at 1519 rpm with torque settings of 40 psi and 70 psi, herein referred to as "partial power" and "cruise power", respectively. Table I lists the conditions for both static and flight tests for which data were obtained. Engine rpm and torque were recorded manually from the pilot's instrument display panel.

Static noise surveys.- Static noise measurements were taken with the microphone array shown in figure 5(a). Microphones were positioned at 30° intervals on a 50-ft radius from the propeller when the engines were operated individually and from a point midway between the two engines when both were operated.

Flyover noise surveys.- Flyover noise measurements were taken with the recording equipment arrayed as shown schematically by figure 5(b). The aircraft was flown at nominal altitudes of 300 and 1000 ft for each engine operating individually and for both engines operating simultaneously as listed in Table I. This was done for engine torque conditions which correspond to speeds of 80 and 160 kts. Altitude and course over the noise measuring equipment were recorded with the aid of a GSN-5 radar tracking unit located adjacent to the 10-28 runway. Radar position information was provided as an assist to the pilot to maintain proper course and altitude. The desired flight path and power conditions were maintained for about one mile prior to and beyond a position over the measuring equipment.

Atmospheric Conditions

During the times of the tests, observations of surface temperature, humidity, wind velocity, and direction were made at a location approximately 2000 ft from the noise measuring station. The temperature varied from 24° to 26°F, the wind velocity was 10 to 12 kts from the northwest, and the relative humidity varied from 46 to 35 percent.

RESULTS AND DISCUSSION

Measured Noise Characteristics of the 02-T Aircraft

Static ground tests.- The noise radiation patterns of the 02-T airplane during static operations of all engine combinations at constant rpm and at two power settings is shown in figure 7. The data are in the form of overall sound pressure levels measured at various azimuth angles around the aircraft, at a radius of 50 ft. Figure 7(a) represents patterns for the front engine, the rear engine, and for both engines operating at cruise power, and figure 7(b) is for partial power conditions. The noise patterns for the single engine operations have a maximum value behind the plane of rotation of the propeller which is in agreement with theory and other experimental data. In addition, generally higher noise levels are also associated with higher torque settings (power level). The figures also indicate that the rear engine alone produces similar radiation patterns but at higher noise levels than does the front engine alone. This may be due in part to differences in the inflow patterns to the front and rear propellers.

With both engines operating the phasing of front and rear propellers is known to be important (See ref. 3) and will account for the cross over of the curves of figure 7(b), and the generally higher values of figure 7(a).

In figure 8 octave band noise spectra are presented for data obtained at the 90° microphone position of figure 7(a) and 7(b). Plotted in figure 8 are the sound pressure levels as a function of frequency for two power settings and for the three engine combinations. Also shown are the overall noise levels for each spectrum. Examination of the data of figure 8 indicate that at both engine power conditions and for all three engine combinations, the maximum sound pressure levels occur in the second octave band. The levels are generally lower for the higher octave bands.

Insight into the sources of noise contributing to the spectra of figure 8 are obtained by means of narrow band analyses (3 Hz constant bandwidth) of the type shown in figure 9. The analyses are shown for front and rear engines operating at a constant rpm at two torque or power settings. These data were taken at the 90° azimuth (plane of propeller) on a 50 ft radius. The top two traces represent the front engine only and the bottom two traces represent the rear engine only. The significant noise components occurred below 500 Hz; therefore, the analyses of figure 9 do not extend above this frequency.

The individual noise components shown as spikes in figure 9 are generally related to the rotational speed of the propeller. These rotational noise components are identified by an mB number where m is the order of the harmonic and B is the number of blades (B = 3 for this airplane. For the front engine only at both power settings (top two traces), the fundamental and one higher harmonic are readily visible. For the rear engine (bottom two traces), rotational components to the 6th harmonic are visible. The relatively high harmonic content of the rear propeller spectrum compared to that of the front propeller may be due to its non-uniform inflow. The broad band noise in all cases shown is thought to be associated with the turbine. The discrete peak occurring at approximately 445 cycles for the front engine is related to the rotational speed of a hydraulic pump. The rear engine does not have such an installation.

Flyby tests.- Figure 10 contains flyover time histories of noise for both the cruise and partial power conditions on the aircraft for the three engine combinations at altitudes of about 300 ft. These data are for on-track measurements taken from one of the three microphones located near the center line of the 10-28 runway. Overall sound pressure levels are shown as a function of time. The zero reference time is approximately the overhead position of the aircraft, and flight direction is from left to right.

For both power conditions and all engine combinations, the noise levels build up to a maximum value when the aircraft is nearly overhead and then decrease as the aircraft continues along its flight path. The maximum cruise power noise levels are 6 to 8 dB higher than those for the partial power condition. Higher noise levels occur generally for two-engine operations, and this is particularly observable at partial power prior to the time overhead.

Noise spectra during the flyover tests are presented in figure 11. The noise levels shown are the maximum values in each octave band time history as the aircraft flies overhead. These levels are shown for each engine combination and for the cruise power (fig. 11(a)) and partial power (fig. 11(b)) modes of operation. Note that these flyover spectra have the same general shape and the noise levels in the mid-band frequency range are the highest. The flyover spectra differ in shape from those of the static tests of figure 8. These differences may be due to such factors as doppler shifts in frequency, difference in propagation distance, difference in directional patterns, as well as in the method of data analysis. The overall sound pressure levels correlate very well with those of figure 8 for each of the engine combinations for comparable distances.

Comparison of the Noise Characteristics of the O2-T and O2 Airplanes

The opportunity is taken to compare the noise characteristics of the O2-T turbine driven propeller aircraft of the present tests with the reciprocating engine version documented in reference 1, a photograph of which is shown in figure 12. The two aircraft are quite similar in geometric features but differ in the type of power plant, the propellers, gross weight, payload, and performance. The noise comparisons are made on the basis of equal altitudes and distances for comparable operating conditions between the reciprocating and turbine powered version.

Static ground tests.- Sample narrow band records of the noise from the front engine only from the O2 and O2-T airplanes are shown in figure 13. These data were obtained by the use of a 3 cps bandwidth filter for data on a 90° azimuth angle and for a distance of 50 ft. The top trace of figure 13 is for the partial power condition of the O2-T airplane and is a repeat of that shown in figure 9. The bottom trace, taken from reference 1, is for the partial power condition of the O2 airplane.

From an inspection of these two traces it can be seen that several noise peaks exist and they can be associated with the propeller rotational and engine firing frequencies. The O2 power plant spectrum contains both propeller and engine components whereas the O2-T spectrum contains only two propeller components plus a component at a frequency of about 440 cps which is associated with the operation of the hydraulic pump. The first harmonic of the propeller rotational noise ($mB = 2$ for the O2 airplane and $mB = 3$ for the O2-T airplane) differ in SPL; the higher level being associated with the O2 airplane. This results from the fact that the fourth engine firing frequency component occurs at the same frequency and apparently adds to the propeller component.

The narrow band noise spectrum of the O2 airplane was analyzed in such a way that the level of the vortex noise (broad band) due to the propeller could be established. This analysis indicated that the vortex noise level was on the order of 60 dB. Based on this finding, the broad band noise of the O2-T trace is judged to be turbine noise rather than propeller vortex noise.

Flyby tests.- Typical time histories of the SPL as obtained during the O2 and O2-T airplane flyover tests for an on-track microphone are shown in figure 14. These data are for partial power operation of the front engine only for both aircraft at the same airspeed. The solid curve (taken from ref. 1) is for the O2 airplane and the dashed curve (taken from fig. 10) is for the O2-T airplane. Note that lower noise levels are associated with the O2-T airplane. At the overhead position they are approximately 10 dB lower and the airplane would probably be heard for a shorter period of time prior to and after overhead.

Although the above data are for the front engine only, they are also believed to be representative of the other engine combinations.

A comparison of the flyover noise characteristics of both aircraft at slow forward speed conditions can be made by examination of the noise spectra plots of figure 15. The maximum sound pressure levels in each octave band are plotted as a function of octave band center frequency. These data were obtained for the O2 airplane (blocked in symbols) and the O2-T (open symbols) for all engine combinations tested at an altitude of 300 ft. It can be seen that the noise spectra of the O2 airplane are generally higher than those of the O2-T airplane. This is an associated 8 to 10 dB difference in the overall levels and this difference is accounted for by differences at both the low and high ends of the spectra.

CONCLUDING REMARKS

Noise measurements have been obtained on a CESSNA O2-T turbine powered propeller driven airplane during static and flyby operations. The noise data are correlated with airplane operating conditions and the mechanical and aerodynamic sources which produce the noise are indicated. Comparison of the overall noise characteristics of the turbine powered airplane with those obtained for a reciprocating engine powered airplane in other studies indicate that the turbine version is 8 to 10 dB quieter.

REFERENCES

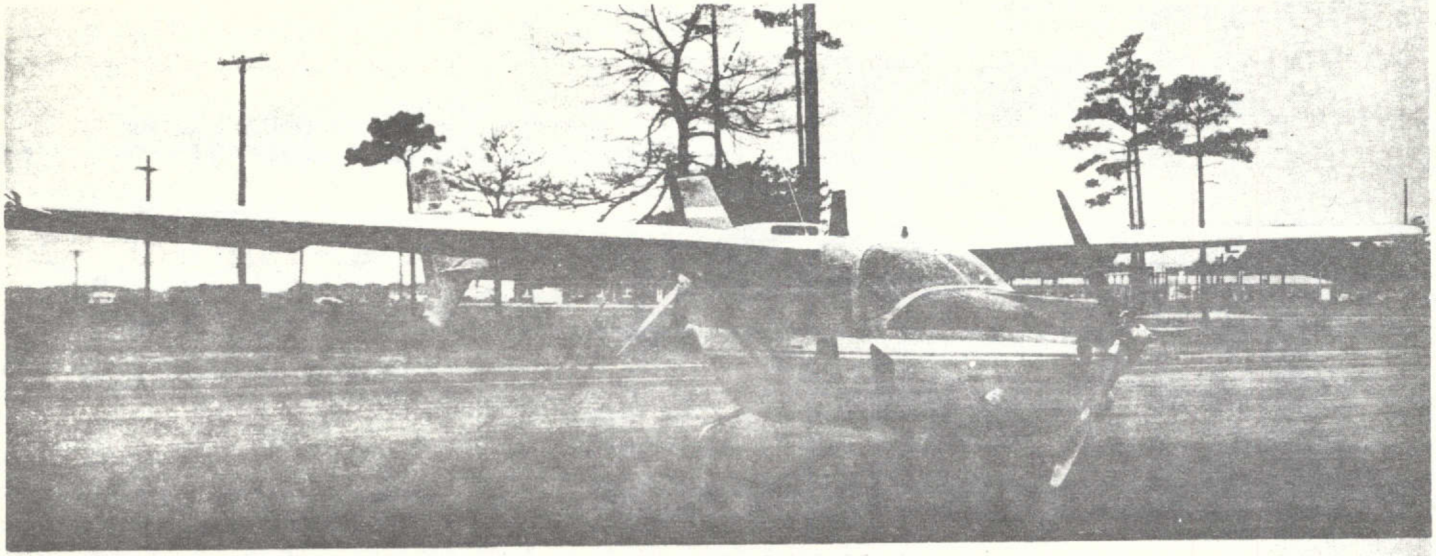
1. Connor, Andrew B.; Hilton, David A.; and Dingeldein, Richard C.: Noise Reduction Studies for the Cessna Model 337 (O-2) Airplane. NASA TM X-72641, January 1975.

2. Anon.: Measurements of Aircraft Exterior Noise in the Field. Society of Automotive Engineers, Inc., Aerospace Recommended Practice ARP 796, June 15, 1965.

3. Hubbard, H. H.: Sound From Dual-Rotation and Multiple Single Rotation Propellers. NACA TN 1654, 1948.

TABLE I.- SUMMARY OF O2-T AIRCRAFT OPERATING CONDITIONS FOR BOTH STATIC AND FLY-BY NOISE MEASUREMENTS.

ITEM NO.	RUN NO.	ALTITUDE ABOVE GROUND, FT.	LATERAL DISP. FROM TRACK ℄, FT.	SLANT RANGE, FT.	IAS, KTS.	ENGINE NO. 1 PROP. RPM	ENGINE NO. 1 TORQUE, PSI	ENGINE NO. 2 PROP. RPM	ENGINE NO. 2 TORQUE, PSI
STATIC									
1	1	---	---	50	---	1519	70	ENGINE SHUT DOWN	
	2	---	---	50	---	1519	40	ENGINE SHUT DOWN	
2	1	---	---	50	---	1519	70	1519	70
	2	---	---	50	---	1519	20	1519	20
3	1	---	---	50	---	ENGINE SHUT DOWN		1519	70
	2	---	---	50	---	ENGINE SHUT DOWN		1519	40
FLIGHT									
1	1	280	20	281	118	1519	70	ENGINE SHUT DOWN	
	2	320	0	320	89	1519	40	ENGINE SHUT DOWN	
2	1	280	10	280	160	1519	70	1519	70
	2	340	20	341	92	1519	20	1519	20
3	1	300	50	304	122	ENGINE SHUT DOWN		1519	70
	2	320	20	321	89	ENGINE SHUT DOWN		1519	40
4	1	1000	150	1011	120	1519	70	ENGINE SHUT DOWN	
	2	1030	100	1035	80	1519	40	ENGINE SHUT DOWN	
5	1	1010	120	1017	161	1519	70	1519	70
	2	1020	140	1030	98	1519	20	1519	20
6	1	1020	10	1020	125	ENGINE SHUT DOWN		1519	70
	2	1000	50	1001	92	ENGINE SHUT DOWN		1519	40



(a) front quartering view

(b) rear quartering view

FIGURE 1.- PHOTOGRAPHS OF THE CESSNA O2-T TURBINE ENGINE POWERED AIRPLANE.

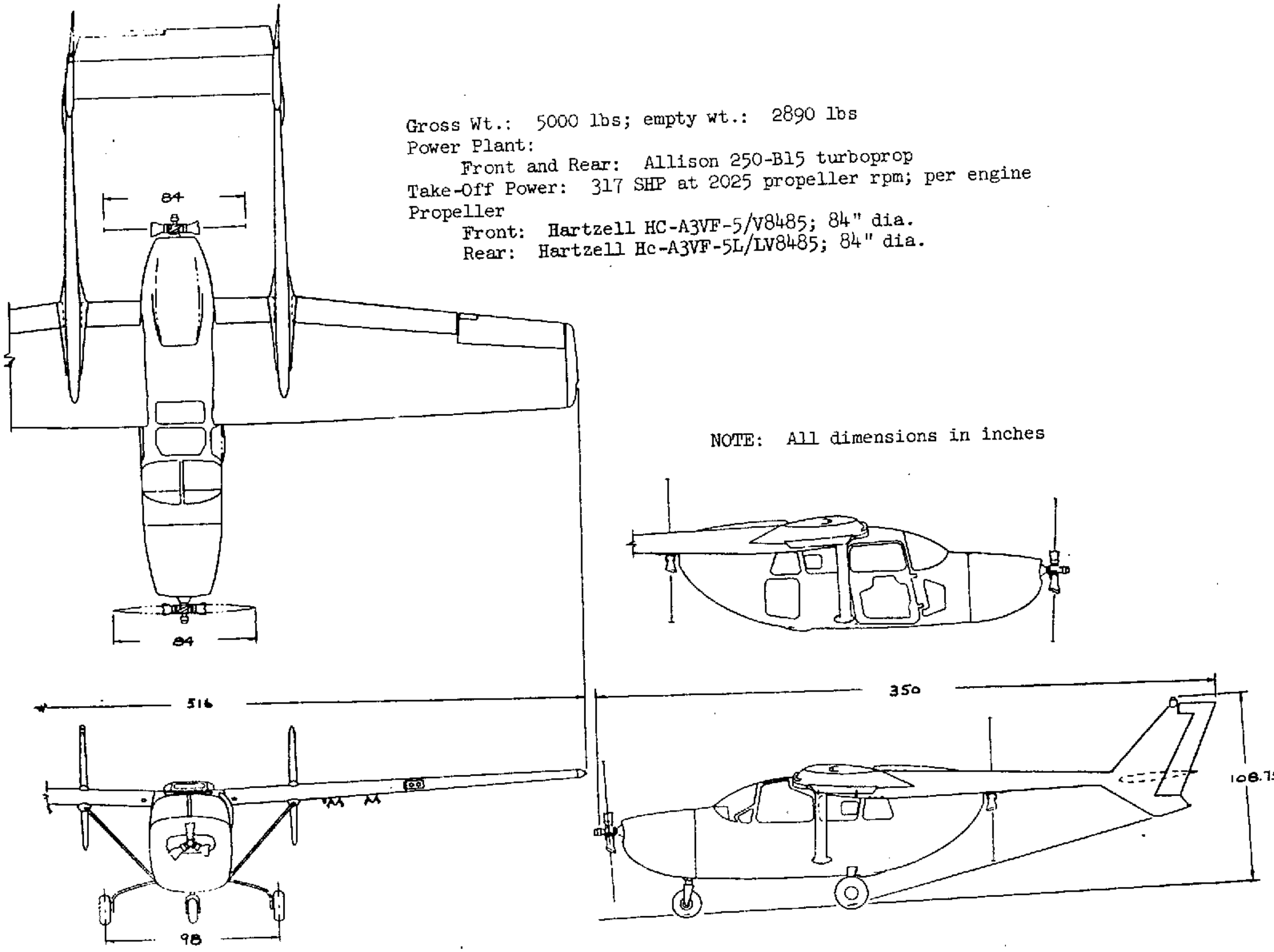


FIGURE 2 THREE VIEW SKETCH OF THE O2-T TEST AIRPLANE ALONG WITH A LISTING OF ITS PHYSICAL FEATURES.

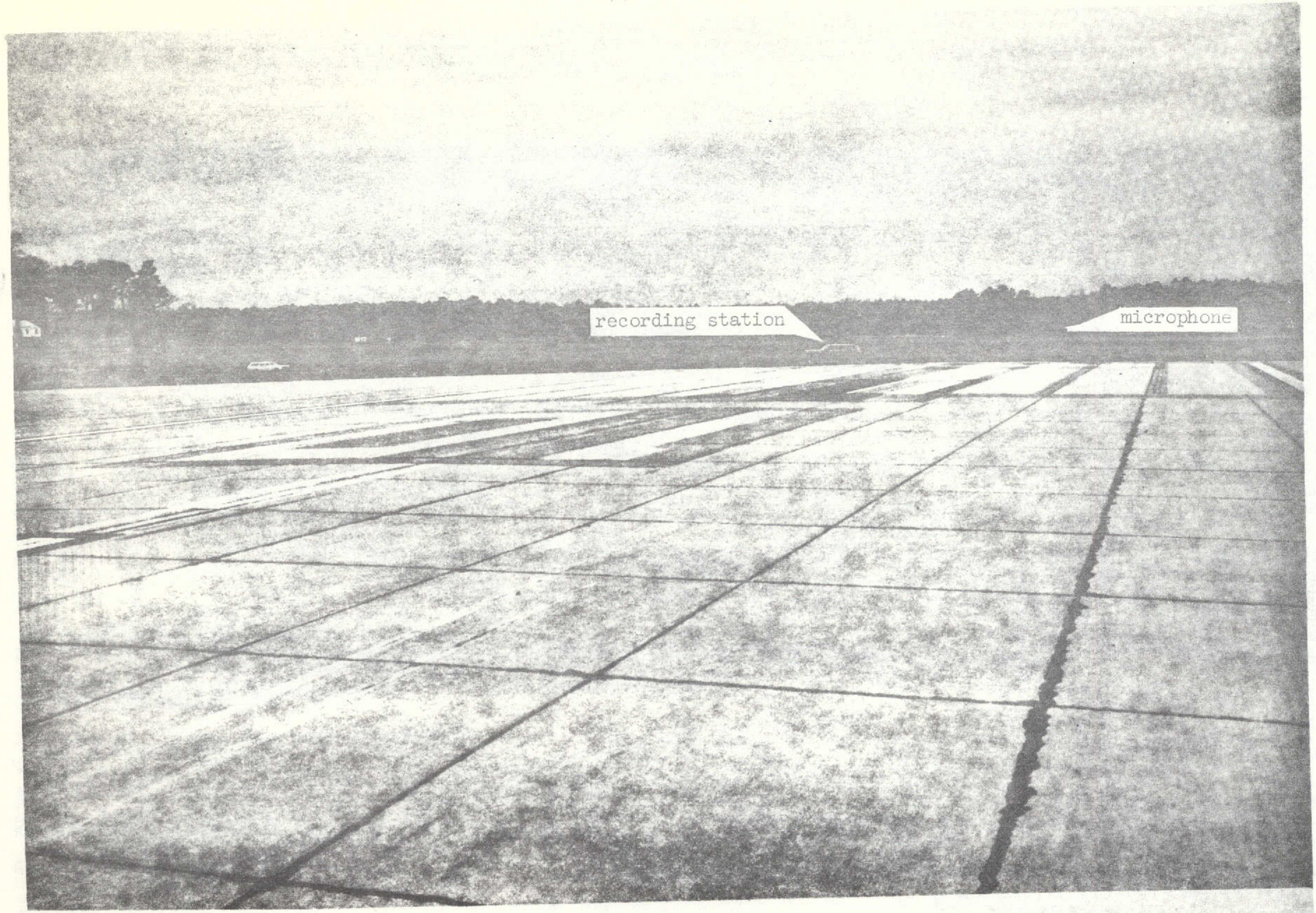


FIGURE 3.- PHOTOGRAPH SHOWING TYPICAL FIELD NOISE MEASURING STATION.
(VIEW LOOKING WEST)

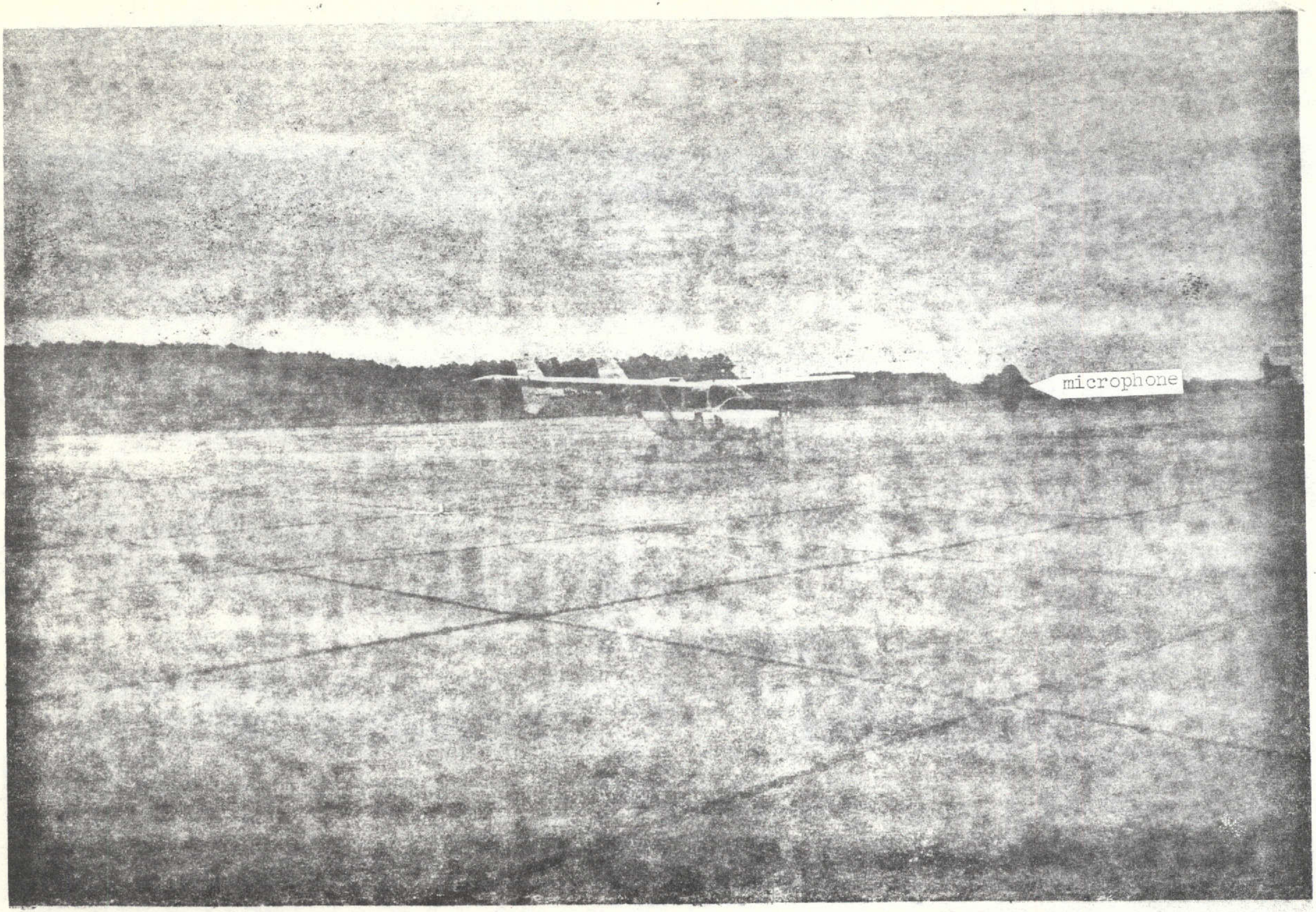


FIGURE 4.- PHOTOGRAPH OF O2-T AIRPLANE DURING STATIC TESTS.
(VIEW LOOKING EAST)

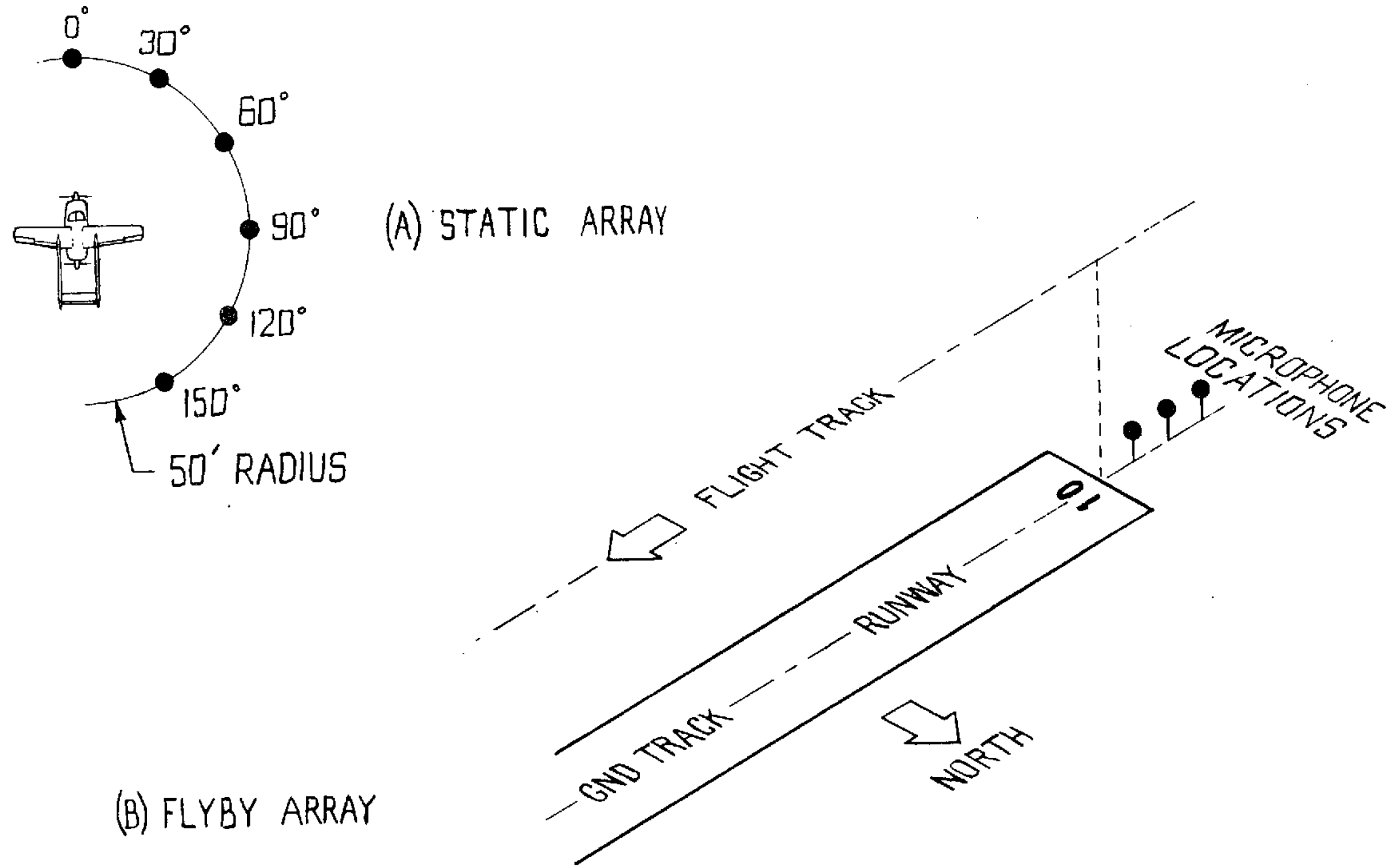
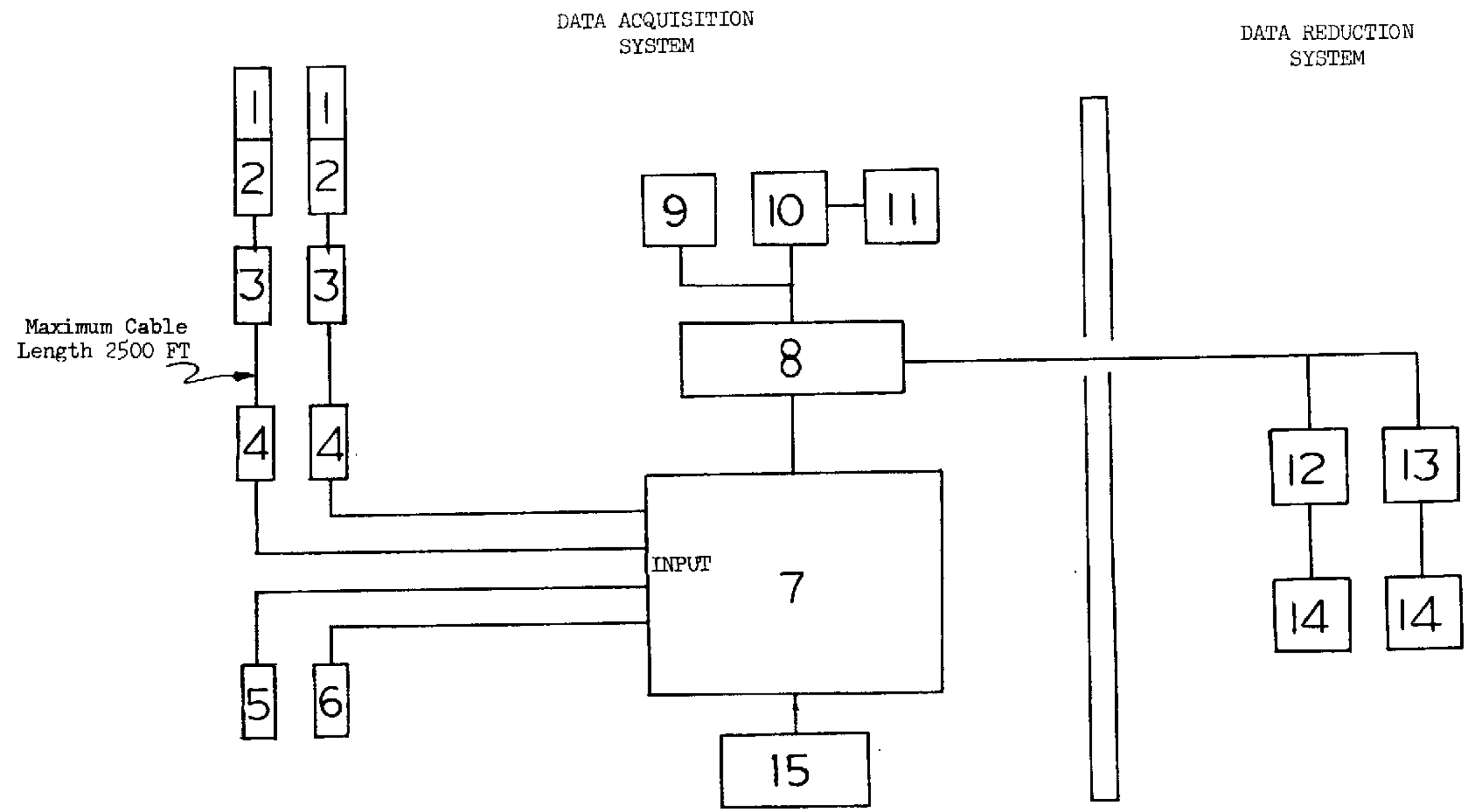
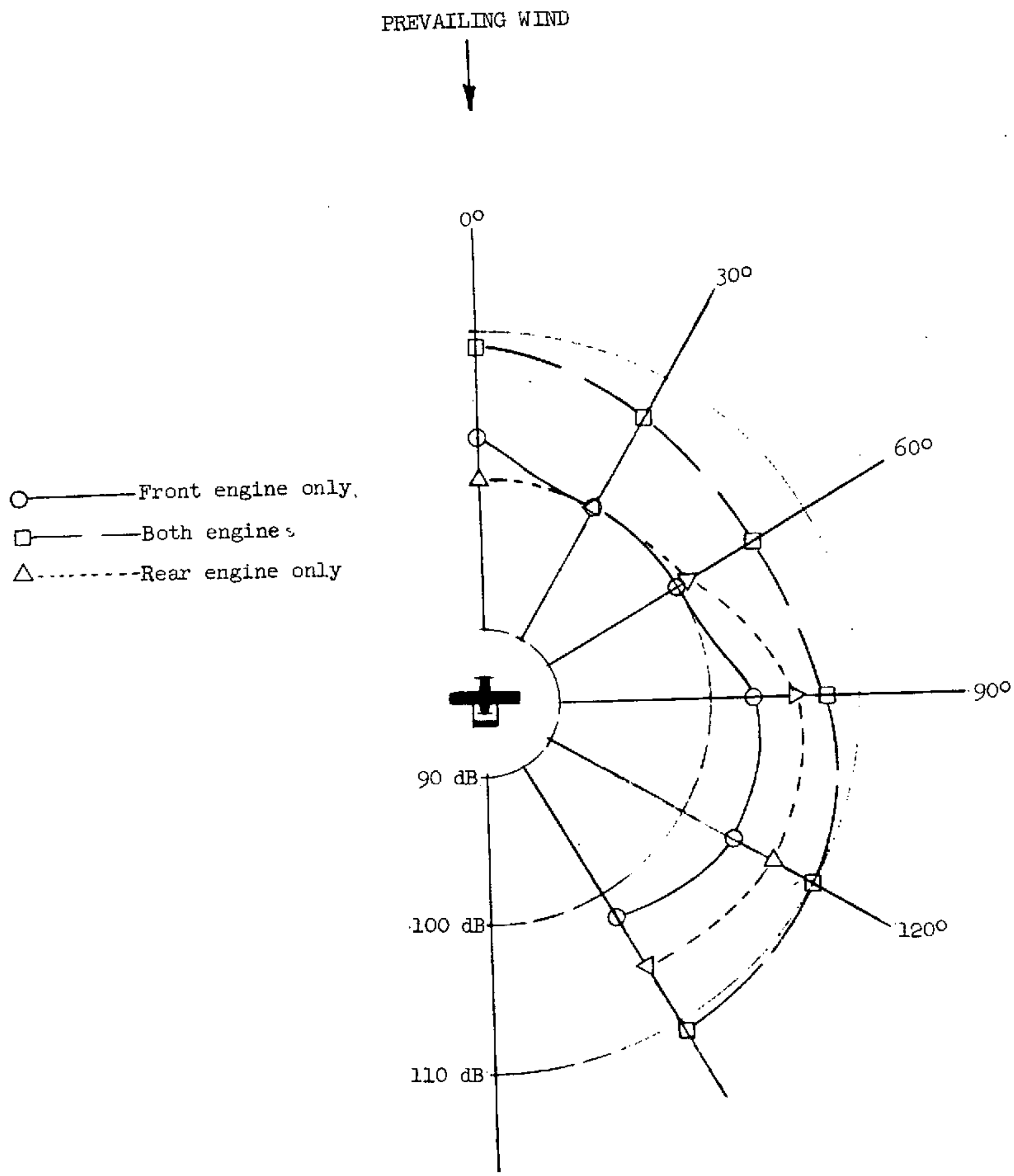


FIGURE 5 DIAGRAM OF THE MICROPHONE ARRAYS ILLUSTRATING THE AIRCRAFT LOCATION FOR NOISE MEASUREMENT DURING STATIC AND FLY BY OPERATIONS.



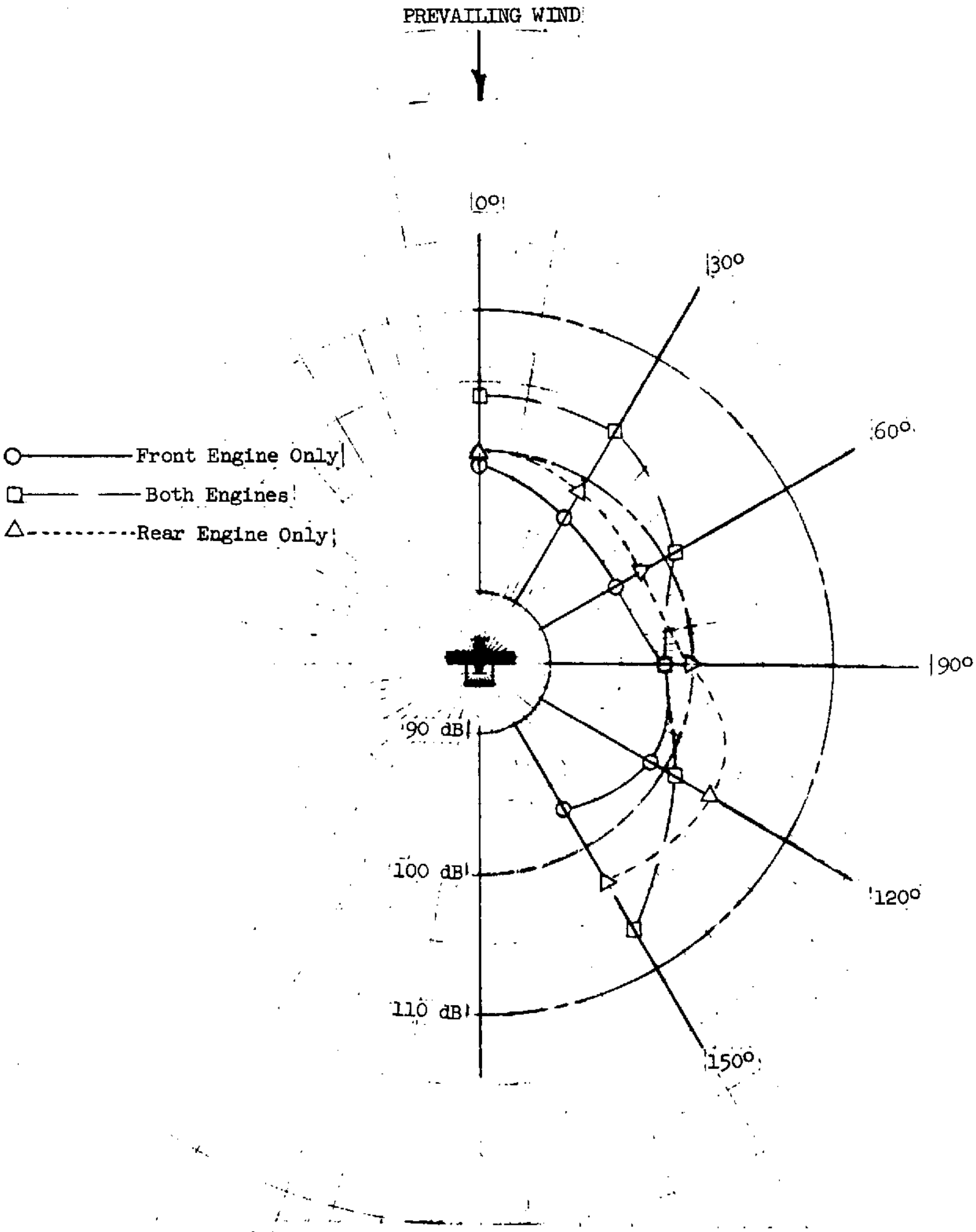
1. GR TYPE 1560-P5 MICROPHONE
2. GR TYPE 1561-P40 PREAMPLIFIER
3. BOOSTER AMPLIFIER (NASA)
4. GR TYPE 1551-CS3 SOUND LEVEL METER
5. 15 WATT FM TRANSCEIVER
6. VOICE MICROPHONE
7. BELL AND HOWELL VR-3300 TAPE RECORDER
8. TAPE RECORDER MONITOR SWITCH BOX
9. TEKTRONIX MODEL 422 OSCILLOSCOPE
10. BELL AND HOWELL DC AMPLIFIER MODEL 1-163
11. HONEYWELL OSCILLOGRAPH MODEL 1508
12. GR TYPE 1558 OCTAVE BAND ANALYZER
13. GR TYPE 1900-A WAVE ANALYZER
14. GR TYPE 1521 - B GRAPHIC LEVEL RECORDER
15. 110 V AC HOMELITE GENERATOR

FIGURE 6 - BLOCK DIAGRAM SHOWING TYPICAL SYSTEM LAYOUT FOR NOISE DATA ACQUISITION AND PRELIMINARY REDUCTION.



(a) cruise power, 1519 rpm, 70 psi torque

FIGURE 7.- OVERALL NOISE RADIATION PATTERN FOR O2-T AIRCRAFT DURING STATIC GROUND OPERATIONS. DATA WERE MEASURED ON A 50-FOOT RADIUS.



(b) partial power, 1519 rpm, 40 psi torque

FIGURE 7.- CONCLUDED.

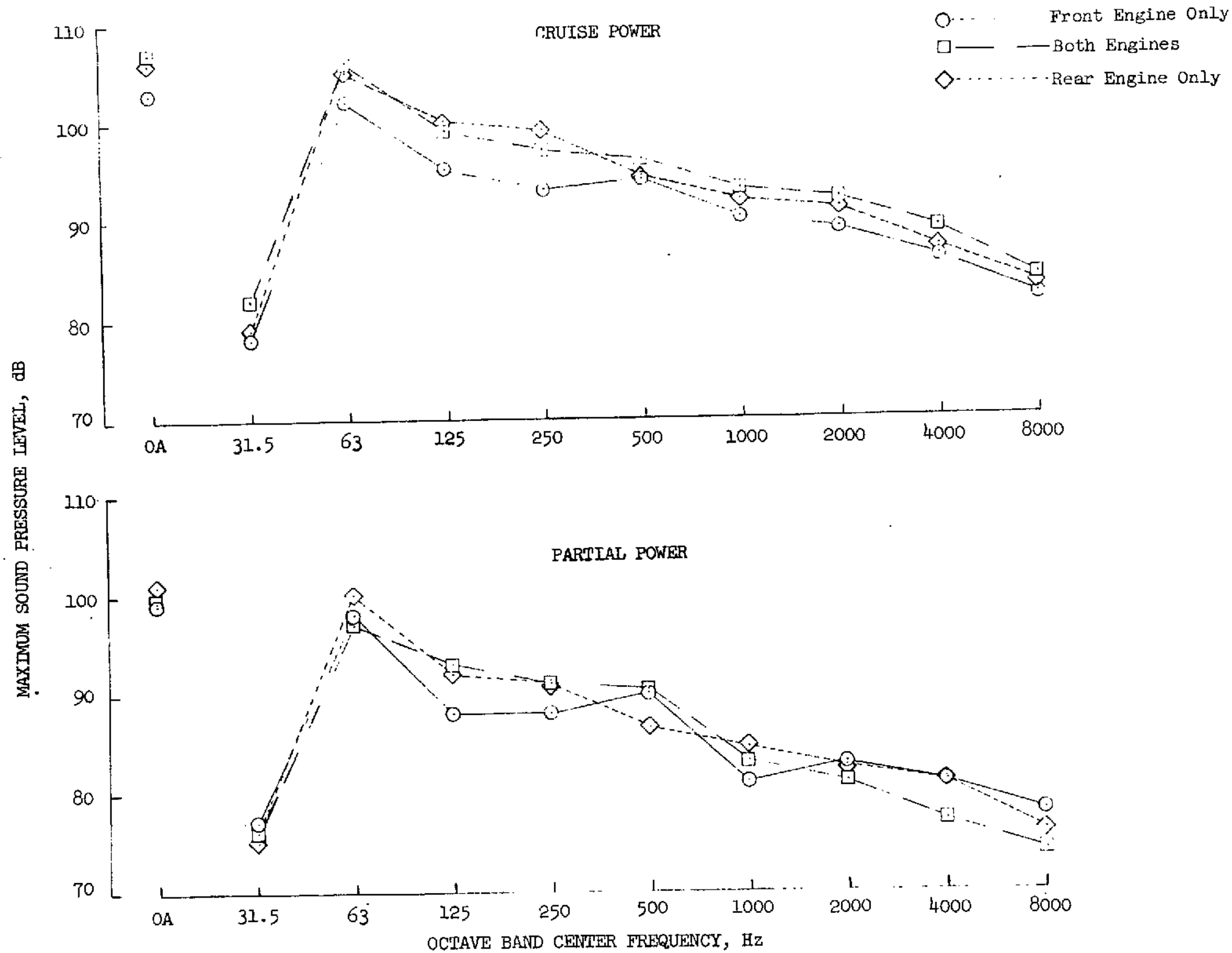


Figure 8 .- Octave band spectra of noise from O2-T aircraft during static ground operations. Data were measured on a 50 foot radius at 90° azimuth location. (i.e. plane of propeller)

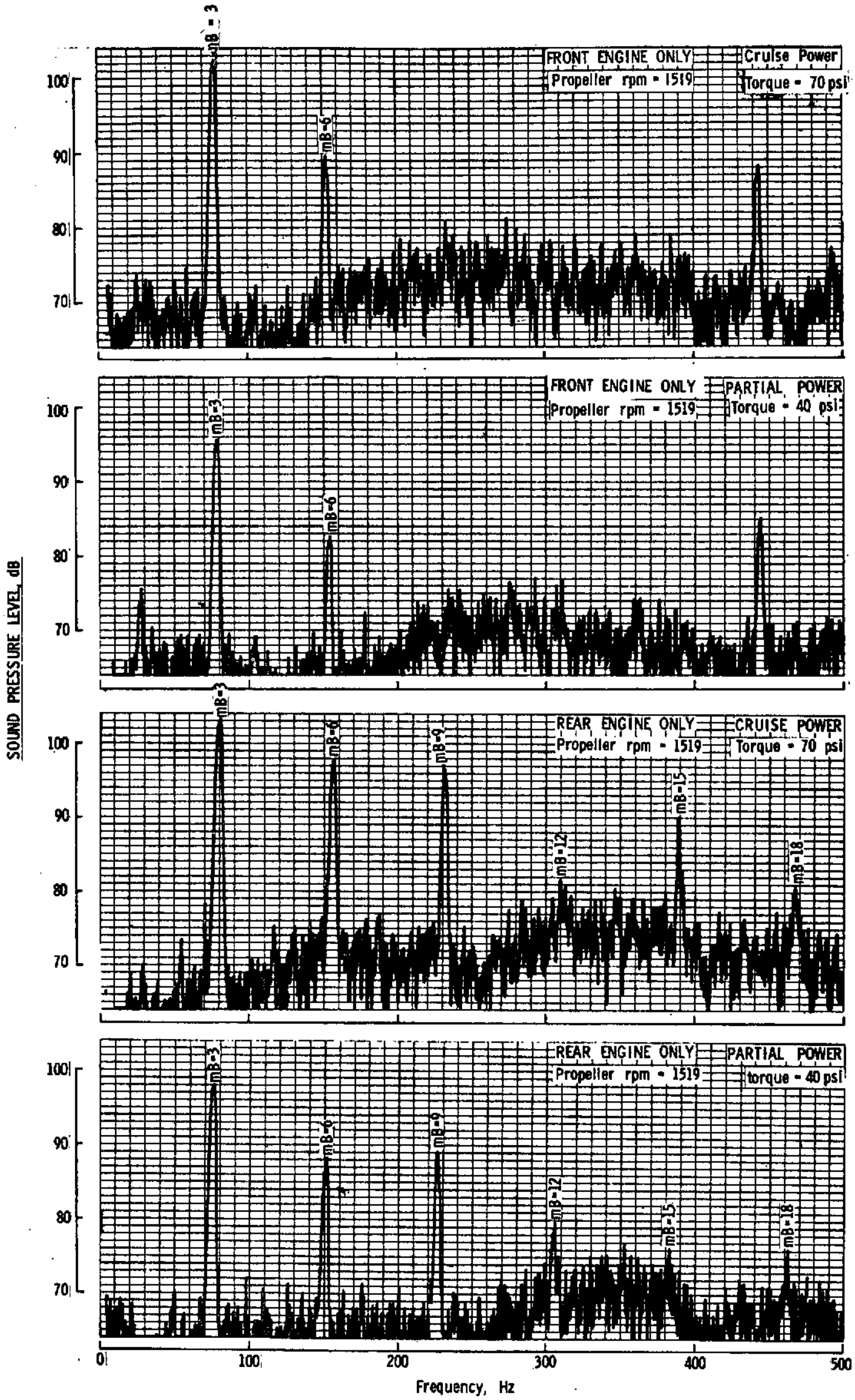


Figure 9 Sample narrow band records of the propeller noise from the 02-T aircraft at various engine operating conditions. Data were measured on a 50-foot radius at 90° azimuth location (i.e. plane of propeller).

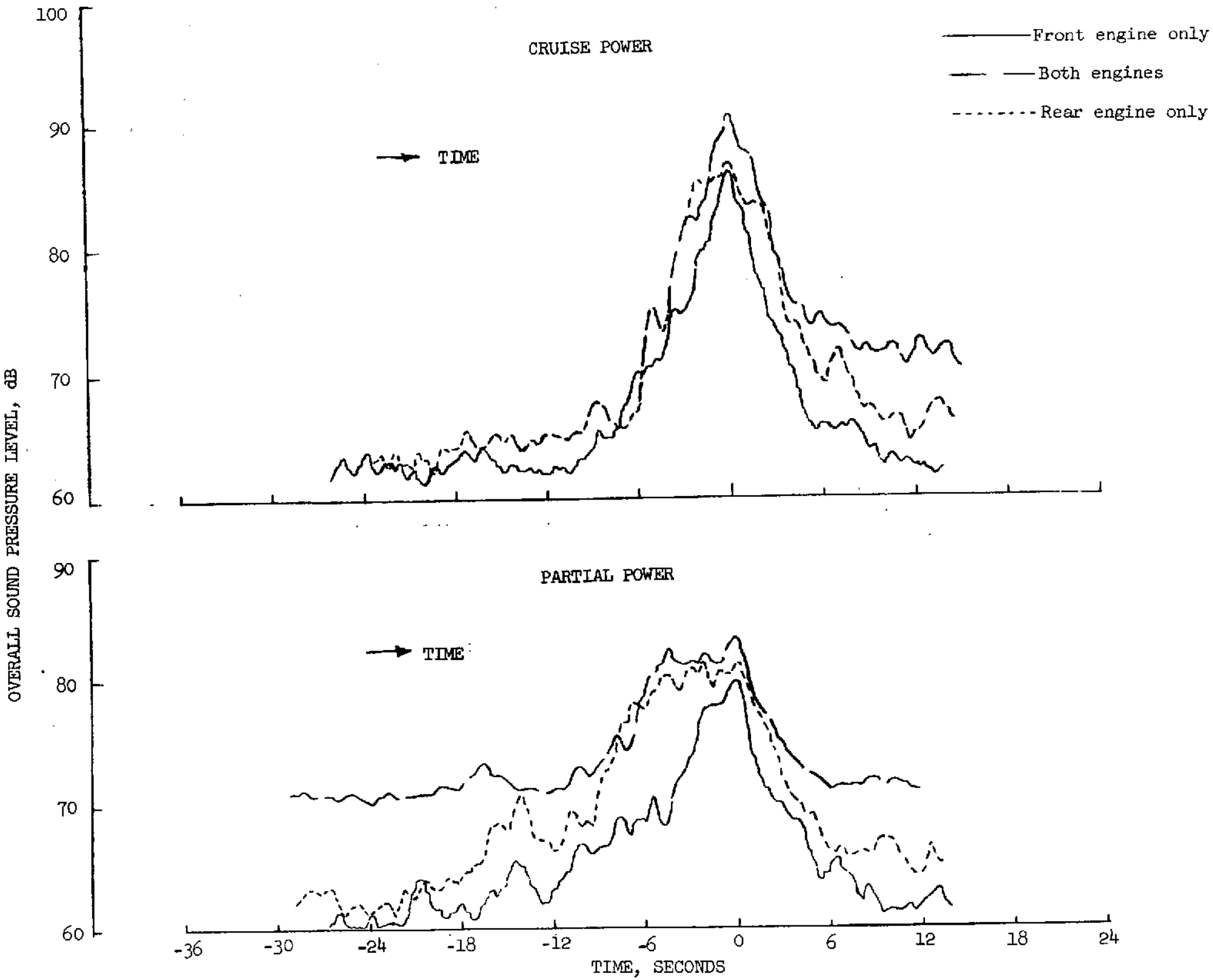
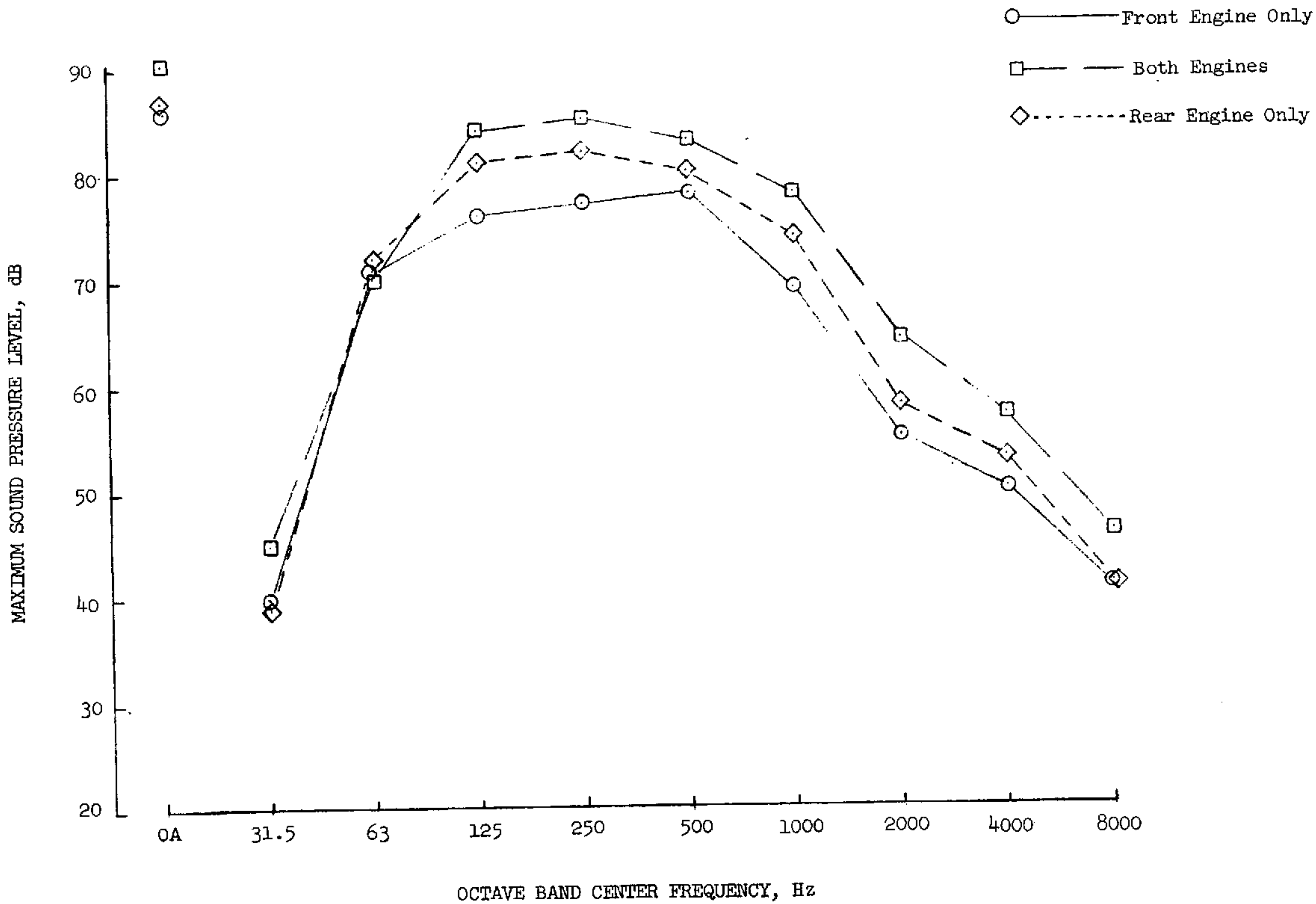
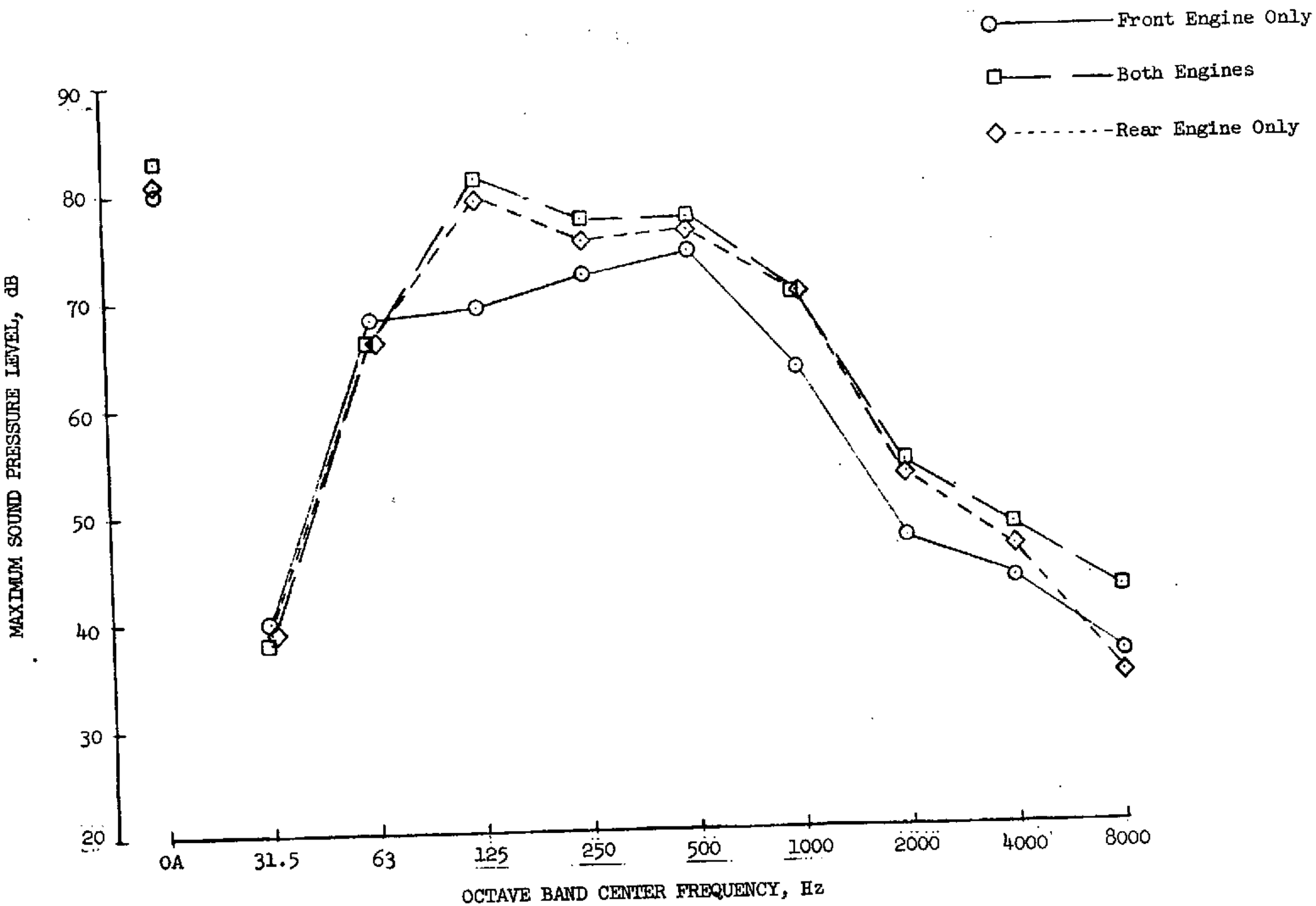


Figure 10 .- Typical time history of sound pressure level as obtained during the 02-T flyover noise test at 300 ft altitude.



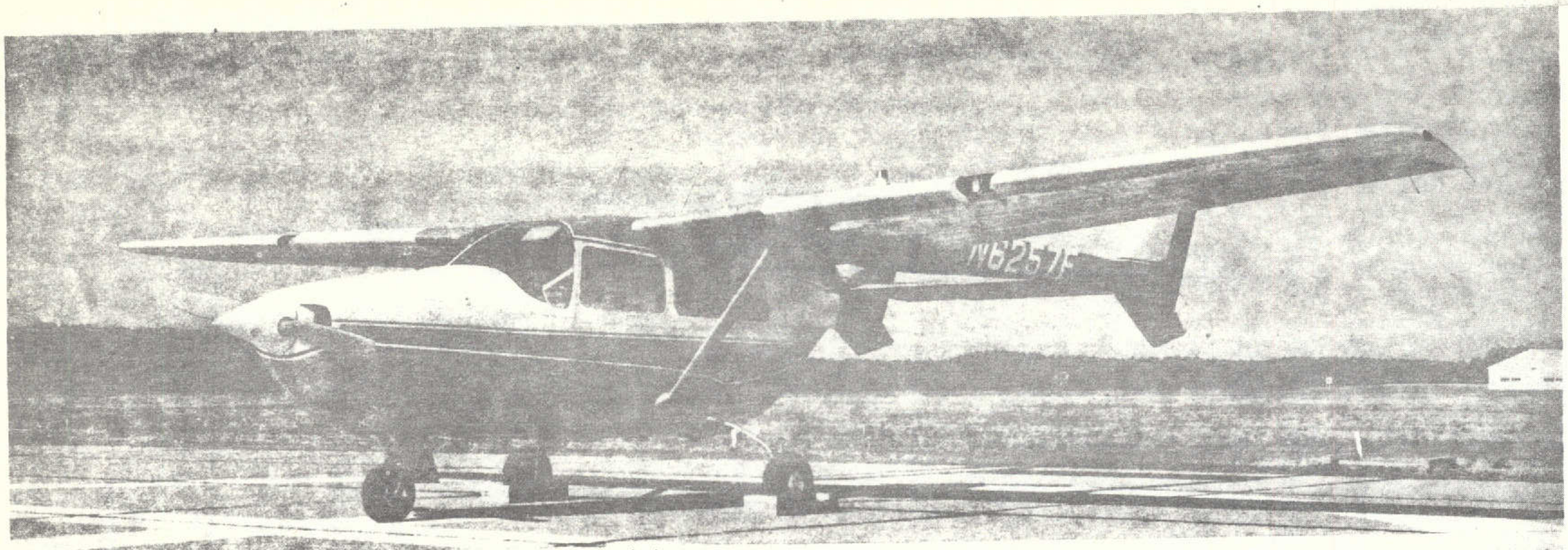
(a) cruise power, 1519 rpm, 70 psi torque

FIGURE 11.- MEASURED NOISE SPECTRA FOR THE O2-T AIRCRAFT IN CRUISE FLIGHT AT 300 FT ALTITUDE AT TWO ENGINE POWER SETTINGS.

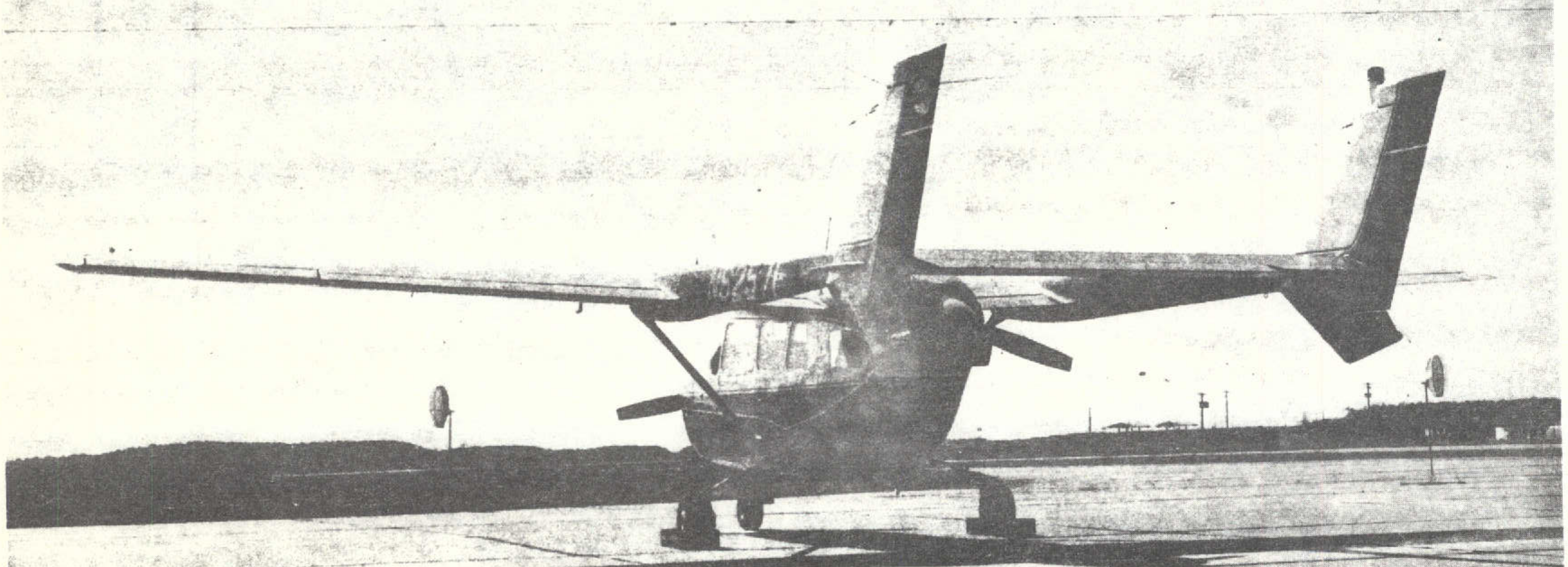


(b) partial power, 1519, 40 psi torque

FIGURE 11.- CONCLUDED.



(a) front quartering view



(b) rear quartering view

FIGURE 12.- PHOTOGRAPHS OF THE O2 RECIPROCATING ENGINE POWERED AIRPLANE.

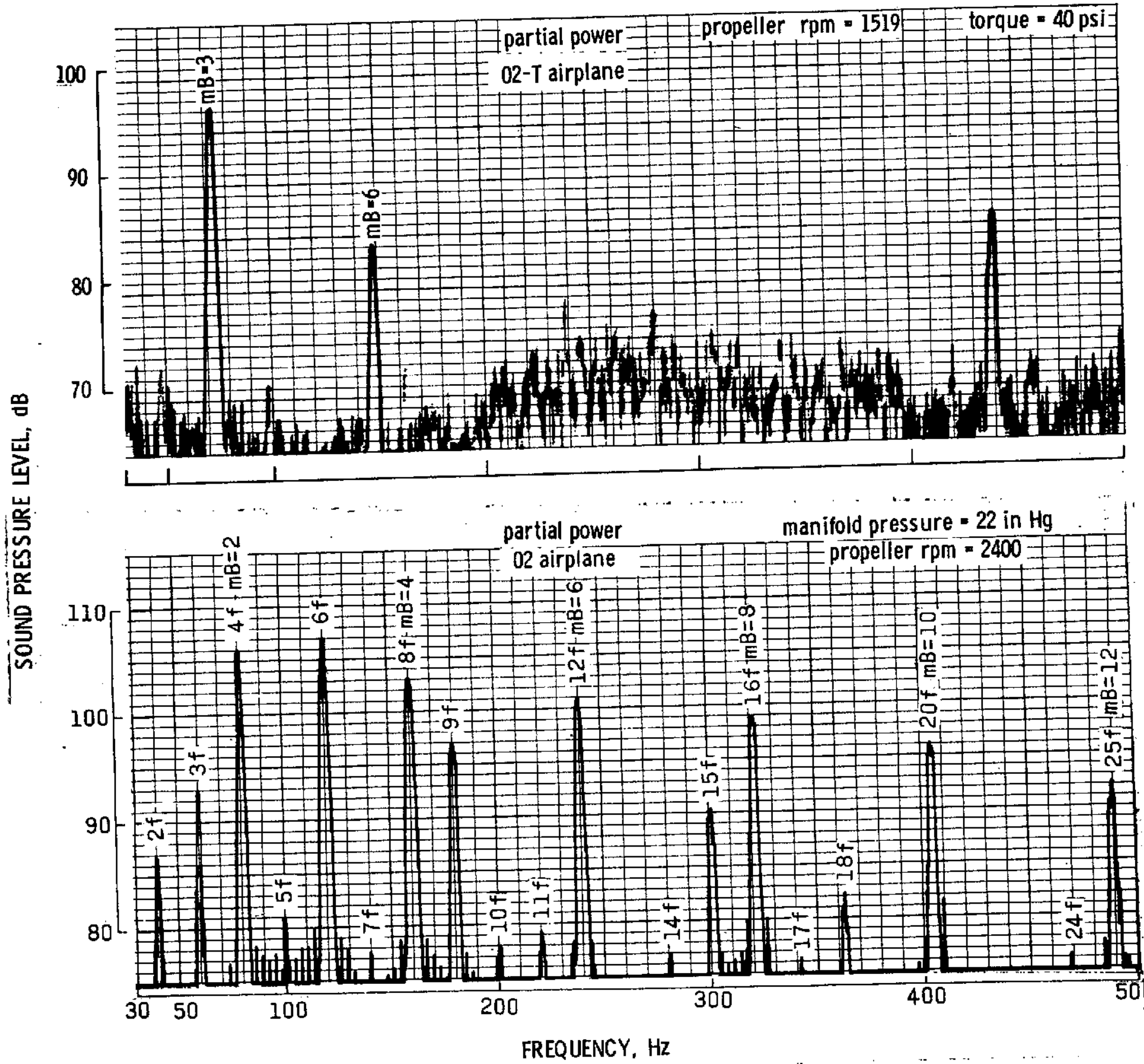


Figure 13 .- Sample narrow band records of the noise from the 02 and 02-T airplanes. Front engine operating, rear engine off, data were measured on a 50 foot radius at 90° azimuth location. (i. e. plane of propeller)

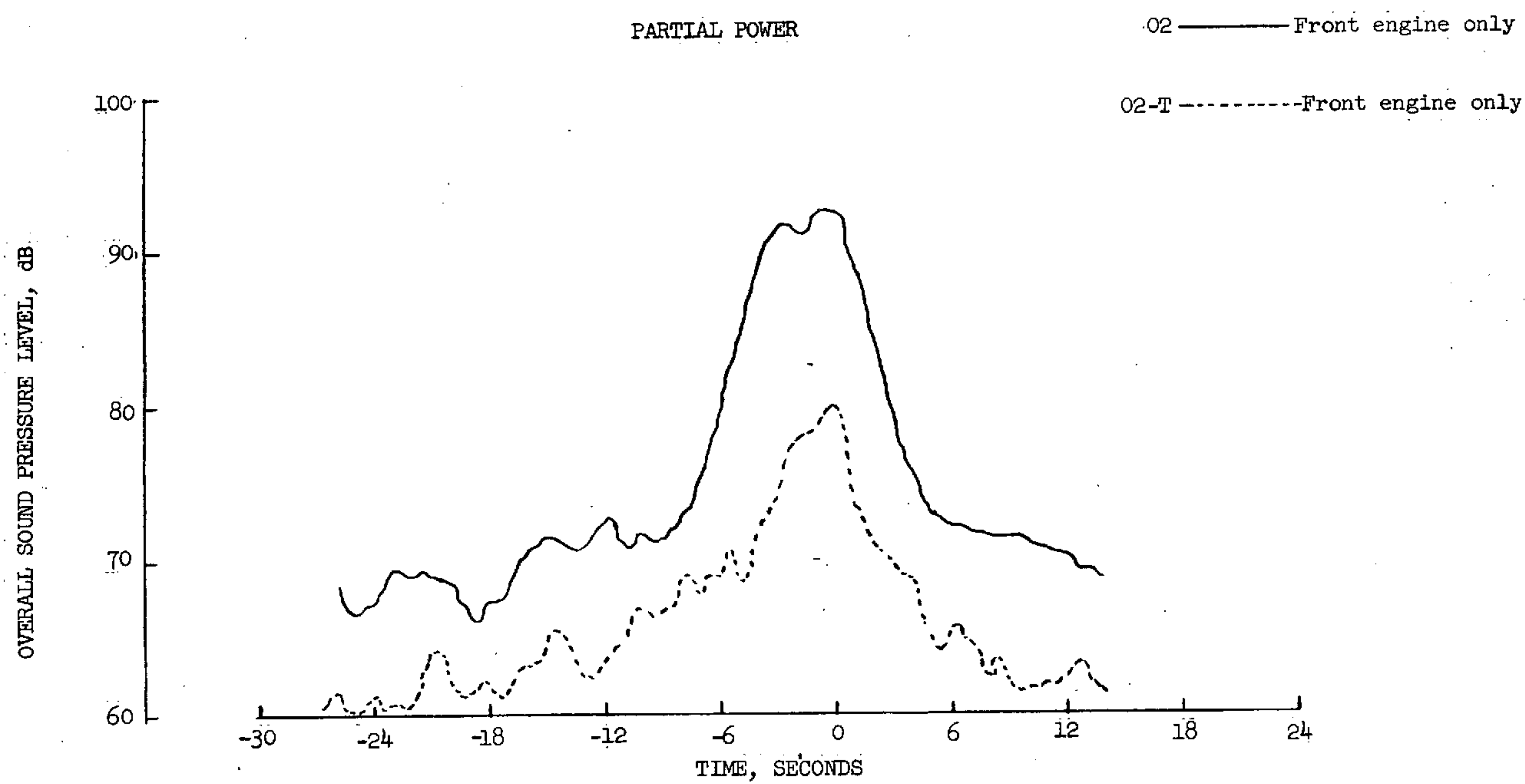


Figure 14 .- Typical time history of sound pressure level as obtained during the 02 and 02-T flyover test at 300 ft altitude.

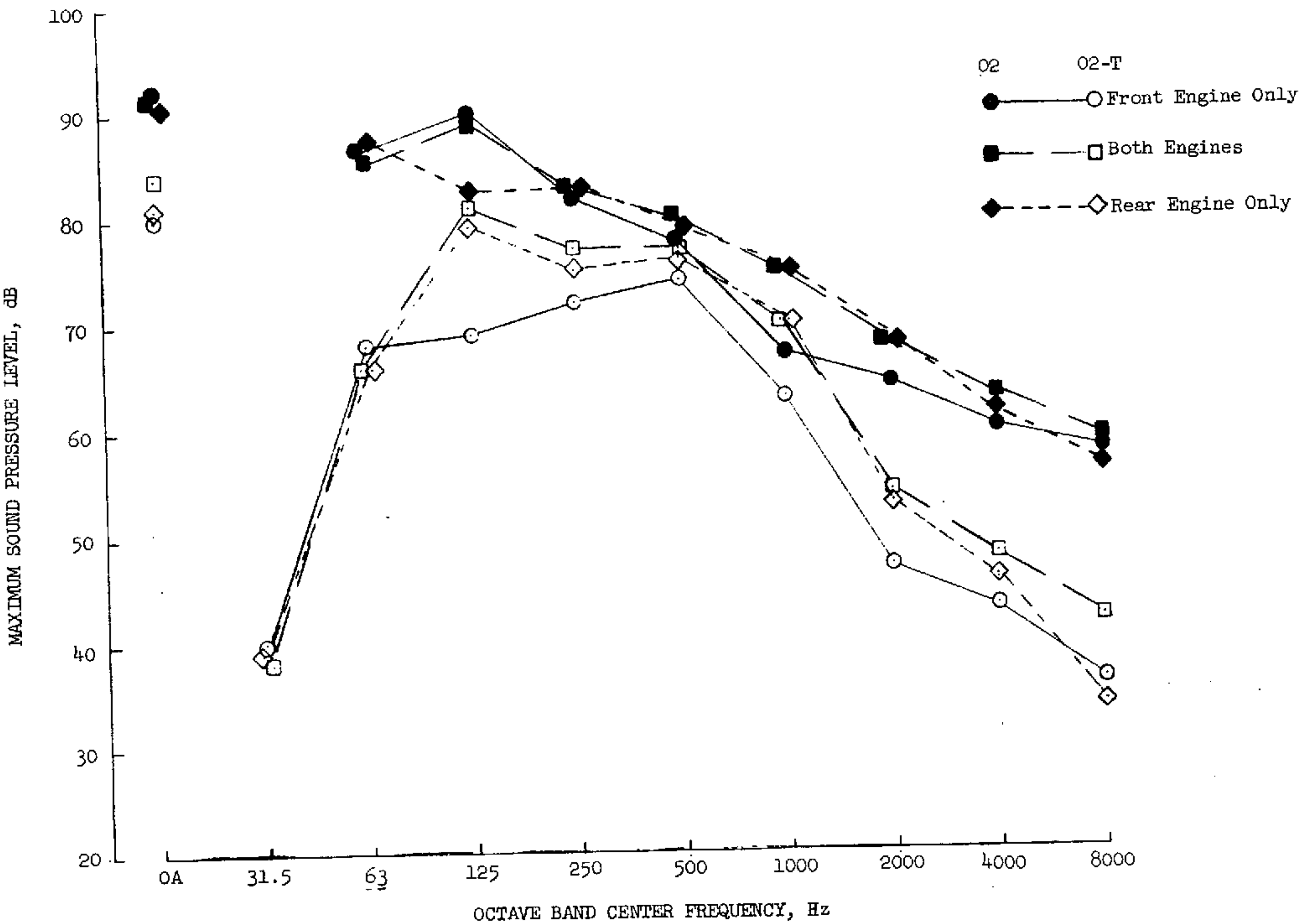


FIGURE 15.- MEASURED NOISE SPECTRA FOR THE 02 VERSUS 02-T AIRCRAFT IN SLOW FLIGHT AT 300 FT ALTITUDE.